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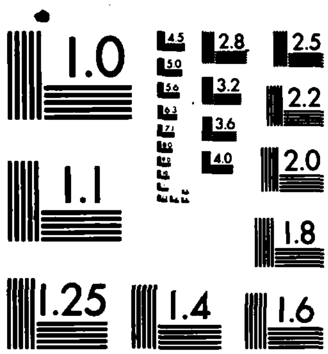

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MTIAC TA-85-01

ARTIFICIAL INTELLIGENCE APPLICATIONS IN MANUFACTURING

October 1985

James H. Cook, Ph.D.
IIT Research Institute

Prepared By:
Cresap, McCormick and Paget
Division of TPF&C, Inc.
Under Contract to
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A Department of Defense Information Analysis Center

Overview

MTIAC is a Department of Defense (DoD) Information Analysis Center. MTIAC serves as a central source for currently available and readily usable data and information concerning manufacturing technology. The primary focus of the Center is to collect, analyze, and disseminate manufacturing technology for the production of defense materials and systems.

The funding agency for MTIAC is the Defense Technical Information Center of the Defense Logistics Agency of the Department of Defense, in Alexandria, Virginia. MTIAC's data collection and dissemination function is tied to DTIC by a shared bibliographic data base.

The DoD supports manufacturing technology programs conducted by the Air Force, Navy, and Army as well as by the Defense Logistics Agency. MTIAC's role is to support the effective use of manufacturing technology by DoD agencies and the industrial contractor base, at both the prime contract and subcontract level. This support is provided through a range of services from technical inquiries to bibliographic searches and special tasks within the scope of the contract. Services are offered on a fee-for-service basis to subscribers and nonsubscribers.

MTIAC Objectives

The Department of Defense established the Manufacturing Technology Information Analysis Center (MTIAC) through the Defense Logistics Agency to improve productivity, reduce costs, and reduce lead times in the production of defense equipment and to further the use and development of advanced technologies. By consolidating and retaining manufacturing information and experience in a central repository staffed by manufacturing specialists, knowledge can be disseminated and applied quickly and effectively to plant modernization programs. The Center benefits engineers and information specialists, government agencies, and defense contractors by saving valuable man-hours in locating data and information and applying the new technologies. The result can be reduced planning and/or production costs.

MTIAC also serves the civil sector within the constraints of the priorities of defense needs and limits on disseminating information, because of security classification, and the export laws and regulations on technology transfer.

Scope of the Program

Activities Scope

MTIAC performs these activities:

- Maintains a bibliographic data base on manufacturing technology
- Maintains a DoD Manufacturing Technology Program (MTP) data base
- Prepares and publishes handbooks, data books, reference works, state-of-the-art reviews (SOARs), critical reviews and technology assessments, conference proceedings, newsletters, and other publications
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production expert systems begin to appear. This won't be without problems, however.

Several references are recommended for initial reading in AI, and lists of products, programs, and players in the field are included.

THE MANUFACTURING TECHNOLOGY INFORMATION ANALYSIS CENTER (MTIAC)

The objective of MTIAC is to support the Department of Defense in achieving an improvement of the productivity and responsiveness of the defense industrial base. This support is to be provided chiefly through the collection, analysis, and dissemination of timely manufacturing technology information and the provision of technical services. The dissemination to the MTIAC customer base is through support to inquiries and the development of products.

The Center concerns itself with areas of manufacturing technolgy that are applicable to defense systems. These areas include but are not limited to: metals, nonmetals, electronics, CAD/CAM, inspection and test, and munitions. The term "manufacturing" covers the entire life-cycle of a product--i.e., design, production and operational support.

Each of the above six subject areas include but is not limited to the defense-related fields of: machine tools and manufacturing equipment, robots and special machines, material handling equipment, controls, software and data-bases, communications lines and networks, sensors and inspection or checkout procedures, signal processing, materials and materials treatments, production processes, the specific defense products being produced and management aspects of manufacturing technology.

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Manufacturing Technology Information Analysis Center

PREFACE

This Technical Assessment was prepared by the Manufacturing Technology Information Analysis Center under Contract DLA 900-84-C-1508, for the Defense Electronic Supply Center. The objective of the Technical Assessment was to evaluate and synthesize the most recent available information in the artificial intelligence field.

CONTENTS

LIST OF TABLES

1. INTRODUCTION

Artificial intelligence (AI) as a technology has been the province of university researchers for about the last 30 years.* The Japanese have sensitized the world business community with increasing successes in manufacturing steel, cars, electronics, and most recently computer chips. When Japan announced their Fifth Generation Project goal, to develop machines that "think", there were immediate reactions. The U.S. Government responded with programs such as the Defense Advanced Research Projects Agency (DARPA) Strategic Computing project, the National Science Foundation (NSF) multidisciplinary engineering research centers, and the Air Force AI in Manufacturing Institute. The British formed the Alvey Committee and the European community formed European Strategic Programs for Resarch and Development in Information Technology (ESPRIT). Private industry responded with cooperative research consortia such as the Microelectronics and Computer Technology Corporation (MCC) and with heavily funded internal research and development (R&D) programs.

For those in manufacturing the result of this activity has been a tremendous number of articles in the trade press extolling the possible manufacturing applications of AI. To those not able to spend a lot of time gathering and sifting through the information it is overwhelming. The purpose of this Technology Assessment is to do some information gathering, review the literature, and classify it as to its possible future applications in manufacturing. This is an activity that must be performed at intervals. In the course of this work several good tutorial reports, books, and articles have been discovered. The reader is directed to those for further details where appropriate.

Artificial Intelligence represents an extremely broad technology. The scope for this Technology Assessment embraces vision, robotics, machine

* The use of "technology" in this sense bothers some who believe that AI techniques are not yet sufficiently developed as a body to be called a technology. It is used this way in this report, recognizing that in a strict sense AI might not yet qualify as a technology.

interface, problem solving and inference, learning, knowledge representation, language, cognitive modeling, speech recognition, available languages, and tactile sensing. Some method for limiting the breadth of this brief assessment was needed. The approach taken was to perform a survey of currently available literature to identify good tutorial references and develop a sense of the areas in which the technology is currently experiencing the greatest application. The results of this survey were then discussed with several workers heavily involved in applying AI to further validate the conclusions and to obtain more in-depth material where available.

2. WHAT IS ARTIFICIAL INTELLIGENCE?

Raymond Kurzweil in his article, "What is Artificial Intelligence Anyway?" (1)*, points out that the possibility of thinking machines has been a subject of debate since Charles Babbage was designing his "analytical engine" around 1833. Kurzweil goes on to provide a very interesting account of the development of the roots of the discipline, tracing a path that touches philosophers and mathematicians such as Bertrand Russell and Allen Turing and ends with today's computer scientists such as Herbert Simon and Allen Newell.

Other accounts also make reference to the roots of AI going back more than a century, but the coining of the term AI is usually credited to John McCarthy's use of it in a grant application for a conference he was organizing in 1956 (2). This conference, held at Dartmouth College, brought together researchers in different fields whose common concern was the study of human and machine cognition. It is often associated with the beginning of AI as a discipline.

Artificial intelligence work experienced a surge of popularity in the 1960s when some rather bold assertions were made about near-term capabilities which would appear, especially in the area of machine translation. When these failed to materialize as promised, research money became scarce. Triggered in part by the Japanese announcement of their Fifth Generation Project, in the last few years AI has again become very popular.

The popularity of AI has caused the definition of the discipline to become vague. This has probably been exacerbated by the origins of AI being interdisciplinary, with no single fundamental concept clearly setting the initial limits. One definition that appears often is that AI technology is anything that deals in making a machine (computer or a robot) behave in a way that if done by a human would be considered intelligent. Of course one of the problems with this definition is that it requires a further definition of what is meant by "intelligent" human. Another definition is that AI is any

* Numbers in parentheses refer to list of references at the end of this report.

technology that enables a computer or computer based machine to respond to situations that were not anticipated by the computer programmer.

Kurzweil defines AI by discussing several assertions about what AI is and what it isn't. He makes the point that our concept of intelligence as an attribute is dependent upon the degree to which we understand things. Thus, if we observe a computer responding correctly in a situation and are unable to understand how it could have been able to do so, we might consider it to be exhibiting intelligence. If we later understand how it was done, we will likely classify it as just a rote technique rather than a manifestation of some innate intelligence. Professor Patrick Winston has pointed out, "One of the few requisites of thinking something is intelligent is that you really don't understand it very well." (3) Winston and Kurzweil both echo a sentiment that AI should be defined as those computer science problems currently at the state of the art. Today this includes search-oriented automatic problem-solving and planning techniques, knowledge representation, computational logic, knowledge engineering and expert systems, computer vision, natural language processing, speech recognition, and parallel processing.

Considering it as the state of the art is not a bad way to look at the field. AI is very dynamic, and things that are considered part of it today may not be in a few years. A lighthearted suggestion has been made that the acronym "AI" should represent "anything interesting" instead of "artificial intelligence". As mentioned above, when it is understood, it is no longer interesting and cannot qualify as AI.

There is a concept which seems to be a moderately consistent common denominator in spite of the proliferation of technologies in the AI family. This concept is the reliance on very efficient forms of search to find solutions from the space of all possible solutions. This stands in sharp contrast to the classical approach to problem solution in which a detailed algorithm is derived from first principles which guarantees a solution when all input parameters are established.

Thus when AI is defined as that programming which enables the item being programmed to adapt to conditions not specifically anticipated by the programmer, this enabling may be considered a manifestation of the concept of search.

William Gevarter has written several reports for the National Aeronautics and Space Administration (NASA) and the National Bureau of Standards (NBS) which provide good overviews of AI (4) (5) (6), and has just published a book which is an extension and update of these reports (7). He summarizes the discussion defining AI as follows:

> "... Unlike conventional computer programming, it is knowledge based, almost invariably involves search, and uses heuristics to guide the solution process.
>
> Thus AI can be considered to be built on the following:
>
> - Knowledge of the domain of interest.
> - Methods for operating on the knowledge.
> - Control structures for choosing the appropriate methods and modifying the data base (system status) as required. This contrasts with conventional computer programs, which utilize known algorithms for solution, are primarily numeric (number crunching) in nature rather than symbolic manipulation, and in general do not require knowledge to guide the solution."

For the purposes of this report AI is considered to encompass anything utilizing the current state of the art technologies within computer science which are involved with machine intelligence. There is a thread of continuity in these areas, brought about by the common goal of producing some degree of intelligence in machines. Consider the following:

Search-Oriented Automated Problem-Solving and Planning Techniques: As mentioned above, the concept of search seems to permeate all AI technologies to some extent, and the AI discipline has understandably evolved a rich repertoire of search techniques. For very simple problems, blind search, the random trial of all conceivable possibilities, might be used. However, for any real-world problem the large number of possibilities generally creates what AI people refer to as the combinatorial explosion, and the number of possibilities to be searched is too large for a blind search. Overcoming the combinatorial explosion through the development of efficient search methods is one of the central issues of automated problem solving and planning. Problem solving approaches involving terminology such as "backward chaining", "problem reduction", and "hierarchical planning and repair" have been developed. It is recognized that search techniques alone will work only on simple well structured problems. Thus, most work in this area is now being focused toward using additional information, i.e., "knowledge" about the problem to not only help pick the most efficient search techniques, but also to guide the search in some way.

Knowledge Representation: The evolving use of knowledge to direct the search has created a need to store, modify, and retrieve large quantities of knowledge efficiently. A considerable technology is building in this area involving knowledge representation concepts such as "semantic networks", "frames", "scripts", and "production systems".

Computational Logic: A given knowledge base will directly provide certain information and implicitly represent additional information. The methods of computational logic, i.e., resolution and nonresolution theorem proving, logic programming, and fuzzy logic, are being applied to facilitate access to this implicit information.

Knowledge Engineering and Expert Systems: The addition of knowledge representation and computational logic techniques to search-oriented automated problem-solving and planning has recently found successful application to some real-world problems. The discipline formed around the application of this combination of technologies has been titled knowledge engineering, and its main products are called expert systems.

Computer Vision, Natural Language Understanding, and Speed Recognition: The environment in which a machine resides provides a large knowledge base, and in some problems, this knowledge must be made available for representation to be manipulated through computational logic techniques and/or searched for goal satisfaction. These three technologies play a vital role in the perception of this environment by the machine and thus belong in the AI family of technologies.

Parallel Processing: It has variously been estimated that despite todays developments in very large scale integration (VLSI), orders of magnitude in state of the art processing speeds are required prior to reasonable AI systems becoming available across a broad spectrum of applications. It is true that some successes are reported with todays processing speeds, but these are generally in nonreal-time or contrived environments. Since the processing speed is limited by the speed of light traveling across the processor, improvements must come by making smaller processors or providing more processors working in parallel. Making smaller processors has been the approach for over a decade and should continue for a few more years. However, some fundamental limits in fabrication technology and heat dissipation are anticipated as the circuit elements approach molecular sizes. Taking a cue from nature, research is underway to utilize the parallel approach. Some believe AI will not really arrive until parallel processing does.

The references quoted so far and a few more, (8) through (16), may be worth reading to obtain a better understanding of the various AI technologies. Gevarter's book is a very good single reference for an overview look at the field of AI.

3. THE ROLE OF AI IN MANUFACTURING

3.1 APPROACH

The general literature search provided several articles which directly or indirectly addressed AI in manufacturing. For example, Slautterback (17), as part of a White House Computer Conference on Productivity, has published a description of the manufacturing environment in the year 2000. According to this description, manufacturing will change more in the next 15 years than it has in the last 75, largely through use of computer-aided technology tools being developed for the last 10 years. These tools include:

Computer Aided Design	Computer Aided Manufacturing
Generative Process Planning	Automated Standards
Computer Aided Quality/Inspection	Manufacturing Resources Planning
Robotics/Material Handling	Group Technology
CNC/DNC	

AI is indicated to be the technology that will tie these tools together.

Gevarter (7) gives a rather complete list of AI generic applications which includes the following items directly related to manufacturing:

- Fault diagnosis and repair (machines and systems)
- Operation of machines and complex systems
- Management (planning, scheduling, and monitoring)
- Design (systems, equipment, intelligent design aids, and inventing)
- Visual perception and guidance (inspection, identification, verification, guidance, screening, and monitoring)
- Engineering (chemical and biological synthesis planning, and intelligent design aids)
- Industrial (factory management, production planning and scheduling, intelligent robots, process planning, intelligent machines, and computer-aided inspection)

Herrod and Papas (9) and Miller (18) have also provided current and future AI applications, organized by AI technology, in the general manufacturing area.

AI Technology	Application

Expert Systems	Design
	Maintenance
	Process Control
	  Monitoring
	  Alarm Analysis
	Equipment Diagnosis
	Process Planning
	Scheduling

Machine Vision	Inspection Identification Measurement
Robotics	Welding Material Handling Parts Positioning Assembly Spray Painting
Natural Language Understanding	Data Base Information Retrieval

Voice Recognition	Data Entry
	  Inventory Control
	  Quality Inspection
	NC programming
	Robotics

Speech Synthesis	Control Room Alarms

The above work provides a general statement of how AI can be applied. To take a more in-depth look and provide a qualitative profile of the actual current AI usage, six data bases were accessed, to search for reports of AI usage in manufacturing since 1983. For details of the six data bases, DROLS, NTIS, COMPENDEX, INSPEC, ISMEC and EI Engineering Meetings, see Appendix A. Out of the material obtained from these searches 39 articles were found that addressed AI applications. The proceedings of several conferences were similarly culled, CAM-I 13th Annual Meeting and Technical Conference, IEEE first Conference on Artificial Intelligence Applications, the first Annual Artificial Intelligence and Advanced Computer Technology Conference, the second International Artificial Intelligence and Robotics Conference, and AUTOFACT 6. These items plus other available material netted 17 additional articles.

This was by no means considered exhaustive, however, there was enough information to form an initial profile and serve as a point of departure for further discussions.

3.2 THE INITIAL PROFILE

The articles have been classified according to three attributes; the manufacturing area addressed, the AI technology represented, and the degree to which the application reported is actually being used.

The manufacturing area addressed by each article was identified as either part design, process planning, scheduling, process control, or assembly.

An attempt was made to identify the artificial intelligence technologies according to the selected definition, i.e., search-oriented automatic problem-solving and planning techniques, knowledge representation, computational logic, knowledge engineering and expert systems, computer vision, natural language processing, speech recognition, and parallel processing. It was soon found that this was too precise for the information gathered, and a compromise was devised using three categories; expert systems, AI programming techniques, and machine vision. AI programming techniques became a catch-all for everything other than machine vision and expert systems.

Finally, the degree of use was specified as being actually "in use", "being developed", or "being discussed". Tables 1 through 3 summarize the results. In the tables, references are made to specific articles by author, title, and numbers in parentheses. The complete citation can be obtained from Appendix B.

TABLE 1. AI APPLICATIONS PROFILE - PART DESIGN

AI Technology	Manufacturing Subarea	Degree of use	Author & Title
ES*	Part design	In use	O'Conner. "The learning curve for building large expert systems" (1). Discusses DEC EXCON ES for configuring Vax 11 systems.
ES	Part design	In use	Swift, et al. "AI in engineering design" (2). Describes ES to help an engineer design components for efficient automatic handling.
ES	Part design	In use	Palmer and Machin. "Expert systems in design and manufacturing" (3). Describes several ES for aiding designers of cables and connectors.
AI techniques	Part design	In use	Swift. "Computer based design consultation system" (4). Describes consultation program that helps the designer design easily assembled products.
AI techniques	Part design	Being developed	Bohachevsky, et al. "Intelligent optical design program" (5). Discusses the development of computer programs for designing image forming optical systems.
ES	Part design	Being developed	Matthews and Swift. "Intelligent knowledge based systems for tribological coating selection" (6). Discusses ES that assists designers in the specification and selection of surface coatings.
ES	Part design	Being discussed	Dyer and Flowers. "Automating design invention" (7). Considers potential ES creativity with respect to the design process.
AI techniques	Part design	Being discussed	Bruevich, et al. "AI system for technology design" (8). Discusses a system to automate design procedures.
ES	Part design	Being discussed	Bassi. "From the first line to the prototype (CAD,CAM,FMS) (9). Discusses use of ES as design aids.
ES	Part design	Being discussed	Dixon and Simmons. "Computers that design: expert systems for mechanical engineers" (10). Discusses use of ES in mechanical design.
AI techniques	Part design	Being discussed	Elias. "Computer-aided engineering: the AI connection" (11). Discusses AI technology attributes for preliminary design problems.

*ES = expert systems

TABLE 2. AI APPLICATION PROFILE - PROCESS PLANNING AND SCHEDULING

AI Technology	Manufacturing Subarea	Degree of use	Author & Title
ES	Process planning	In use	Rueher. "The first CAD/CAM expert systems" (12). Discusses ES to generate manufacturing plans for machining and robot movements.
ES	Process planning	In use	Anonymous. "Expert system solves control problems" (13). Discusses ES to develop control strategies for a distillation process.
AI techniques	Process planning	In use	Liu. "Utilization of AI in manufacturing" (14). Discusses system that generates manufacturing instructions and soon will feedback producibility information to the designer.
AI techniques	Process planning	In use	Barkocy and Zdeblick. "A knowledge-based system for machining operation planning" (15). Describes program, CUTTECH, that performs machining operation planning.
AI techniques	Process planning	In use	Szuba. "Automatic program synthesis system for NC machine tools based on PC-PROLOG" (16). Describes system that provides program synthesis for NC machine tools.
AI techniques	Process planning	In use	Preiss and Kaplansky. "Automated CNC milling by AI methods" (17). Describes system that provides program synthesis for NC machine tools.
AI techniques	Process planning	In use	Mill and Spraggett. "AI for production planning" (18). Describes FMS process planner.
AI techniques	Scheduling	In use	Fox. "Constraint-directed search: A case study of job-shop scheduling" (19). Describes ISIS, a job-shop scheduling program.
ES	Process planning	Being developed	Cotter. "The role of decision processing in IMPACT - an integrated NC planning system prototype" (20). Describes an ES for automatic generation of NC programs starting with a solid product model.
ES	Process planning	Being developed	Latombe and Dunn. "XPS-E: An expert system for process planning" (21). Describes process planning ES.

TABLE 2. AI APPLICATION PROFILE - PROCESS PLANNING AND SCHEDULING (continued)

AI Technology	Manufacturing Subarea	Degree of use	Author & Title
ES	Process design	Being developed	Nasr. "A prototype expert system for material handling" (22). Describes ES for the selection of material handling equipment.
ES	Process design	Being developed	Ingrand and Latombe. "Functional reasoning for automated fixture design" (23). Describes ES for automatic fixture design.
AI techniques	Scheduling	Being discussed	Szenes. "An application of a parallel systems planning language in decision support production scheduling" (24). Discusses production scheduling using T.PROLOG.
ES	Process planning	Being discussed	Nof. "An expert system for planning/replanning programmable facilities" (25). Discusses using ES for facility planning.
ES	Process planning	Being discussed	Nau and Chang. "Prospects for process selection using AI" (26). Discusses using ES for process planning.
ES	Process planning	Being discussed	Hall and Putnam. "An application of expert systems in FMS" (27). Discusses using ES for process determination, sequencing, and scheduling.
ES	Process planning	Being discussed	Allen. "Knowledge engineering aspects of AI" (28). Discusses using ES for process planning.
ES	Process planning	Being discussed	Elwell and Jardine. "A machinability model expert system prototype" (29). Discusses use of ES to develop machinability models in the manufacturing planning process.
AI techniques	Process design	Being discussed	Walter. "Control software specification and design: An overview" (30). Discusses use of AI techniques in automatic control.
AI techniques	Process design	Being discussed	Henkel. "Designing space for robots - a complex problem" (31). Suggests use of AI programs for developing floor layouts when using robots.

TABLE 3. AI APPLICATION PROFILE - ASSEMBLY AND PROCESS CONTROL

AI Technology	Manufacturing Subarea	Degree of use	Author & Title
Machine vision	Assembly	In use	Bevan. "Electronic vision now a reality" (32). Discusses machine vision system used for inspection.
Machine vision	Assembly	In use	Anonymous. "Fanuc uses vision to help with assembly" (33). Discusses machine vision system for assembly assistance.
Machine vision	Assembly	In use	Baird. "GAGESIGHT: A computer vision system for automatic inspection of instrument gauges" (34). Discusses machine vision system used for inspection.
Machine vision	Process control	In use	Lapidus. "New techniques for industrial vision inspection" (35). Discusses machine vision system used for inspection.
ES	Process control	In use	Hakaml and Newborn. "Expert system in heavy industry: An application of ICLX in a British Steel Corp. works" (36). Discusses ES to help operate a steel rolling mill.
ES	Process control	In use	Moore, et al. "A real-time expert system for process control" (37). Discusses ES to assist in the process control of a refinery.
ES	Process control	In use	Moore. "Issues for the expert system development environment" (38). Discusses ES to assist in the process control of a refinery.
ES	Assembly	In use	Gliviak, et al. "A manufacturing cell management system CEMAS" (39). Discusses ES to supervise a manufacturing cell.
AI techniques	Assembly	In use	Anonymous. "IBM computer controlled robotic system out" (40). Discusses robotic system for electronic component insertion.
AI techniques	Assembly	In use	Anonymous. "New assembly robot from GEC in U.S." (41). Discusses robot used for assembly work.
ES	Process control	Being developed	Sakaguchi and Matsumoto. "Development of a knowledge based system restoration" (42). Discusses ES for power system restoration assistance.

TABLE 3. AI APPLICATION PROFILE - ASSEMBLY AND PROCESS CONTROL (continued)

AI Technology	Manufacturing Subarea	Degree of use	Author & Title
Machine vision	Assembly	Being discussed	Villers. "Intelligent robots: moving toward megassembly" (43). Robotic applications for machine vision are mentioned.
Machine vision	Assembly	Being discussed	Atkinson. "Some applications of on-line vision sensing in industry" (44). The impact of intelligent sensors on the scope of manufacturing processes is discussed.
Machine vision	Assembly	Being discussed	Okhotsimsky, et al. "Automatic multi-operation assembly and application of visual control" (45). The automation of industrial assembly processes with robots plus simple sensors plus machine vision is discussed.
Machine vision	Assembly	Being discussed	Horn and Ikeuchi. "Picking parts out of a bin" (46). Discussed machine vision as applied to the bin picking problem.
Machine vision	Assembly	Being discussed	Ejiri. "Industrial applications of vision technology" (47). Reviews applications of vision technology in industry.
Machine vision	Assembly	Being discussed	Wagner. "Machine vision: A link in fully integrated manufacturing matures" (48). Provides a general discussion of machine vision capabilities.
Machine vision	Assembly	Being discussed	Branaman. "Look at intelligent vision" (49). Discusses the possible applications of machine vision.
Machine vision	Assembly	Being discussed	Hall and McPherson. "Three dimensional perception for robot vision" (50). Reviews 3-D perception techniques for machine vision.
AI techniques	Assembly	Being discussed	Bellmann, et al. "Automated monitoring of fabrication" (51). Discusses use of AI for monitoring equipment.
AI techniques	Assembly	Being discussed	Dodds. "Spatial planning, geometric modelling and fuzzy production rules in robotic systems" (52). Discusses use of AI for robot planning.

TABLE 3. AI APPLICATION PROFILE - ASSEMBLY AND PROCESS CONTROL (continued)

AI Technology	Manufacturing Subarea	Degree of use	Author & Title
AI techniques	Assembly	Being discussed	Pinto. "AI and robotics applied to process control and factory automation" (53). Discusses practical application of AI in Robotics and Process Control.
AI techniques	Assembly	Being discussed	O'Shima. "Computer aided plant operation" (54). Discusses computer automation of plant operation.
AI techniques	Assembly	Being discussed	Albus, et al. "Sensor robotics in the National Bureau of Standards" (55). Discusses AI techniques for providing control systems with sensory capabilities.
AI techniques	Assembly	Being discussed	Novak. "Process knowledge the key to artificial intelligence use" (56). Discusses the use of AI in machine tool control.

3.3 DISCUSSION

In the "part design" category the applications reported as "in use" or "being developed" are either expert systems or applications programs utilizing AI programming techniques, with expert systems representing two-thirds of the total. The most well-known application is the XCON expert system mentioned in O'Conner's article (Bibliog 1).* XCON was developed initially at Carnegie for Digital Equipment Corporation (DEC). It is used to check the configurations of Vax 11 computer systems on customer orders, and has been reported to be saving DEC about $200,000 per month in staff costs. (19)

Swift, et al (Bibliog 2) discusses two expert systems to aid designers. The first, which is operational, addresses the problem of ensuring that the components being designed can be handled automatically. "For a given component it:

- estimates the costs of handling and assembly equipment,
- advises the designers of difficulties with components present for automatic handling during manufacture, and
- suggests design improvements."

The system's average error in the costing is about 11 percent, slightly higher than the 8 percent experienced by human experts. The second expert system is under development. It addresses the problem of specification of surface coatings or treatment.

One of the most interesting "parts design" articles was that by Dyer and Flowers, (Bibliog 7). They discuss the application of AI to the problem of creative invention. Some previous work on automated invention in the areas of mathematics and scientific discovery is presented, and an illustration of the extension of the same approaches to engineering design is provided. They conclude with the following:

* Numbers so designated refer to Bibliography in Appendix B.

"... creativity and design are not impenetrable barriers. Many aspects of imagination, design and creativity can be formalized and encoded into a machine. This potential is very promising and exciting. However, the research work on creativity, discovery, and invention in AI is only a decade old and should not be judged prematurely."

From this it is concluded that in the area of design AI systems are now used primarily as expert system design aids, providing advice and checking details. AI programming with creativity is not yet ready to challenge human designers.

In the "process planning and scheduling" areas the AI applications reported as "in use" or "being developed" are still either expert systems or applications programs using AI programming techniques. The expert systems have over half of the total.

Perhaps the best known scheduling system that showed up in our literature search is Mark Fox's ISIS system for job shop scheduling (Bibliog 19). The reference uncovered was Fox's doctoral thesis, but it has also been discussed in other articles. (20)

A very interesting expert system application is the Hughes Integrated CLASSification (HICLASS) Software System reported by Liu (Bibliog 14). This system works from CAD data on interactive graphics systems to automatically provide on-line instructions on how to build the product.

A common thread moving through many of the process planning articles was the automatic generation of NC programs, starting with the solid model representation on a CAD system. Preiss and Kaplansky (Bibliog 17) present such a system. Barkocy and Zdeblick (Bibliog 15) discuss a partial solution in the form of a system to aid the NC programmer by selecting cutting tools and pass sizes. Szuba (Bibliog 16) demonstrated a full automatic program synthesis for NC machine tools.

In the assembly area, systems in use or being developed were about evenly split between machine vision and expert systems. Most machine vision applications are in inspection and are just becoming able to use gray scale images (for instance see Bibliog 36). A Robot News International report

(Bibliog 33) relates the use of vision systems for actual assembly operations at Fanuc, but the impression from other articles is that such applications are still uncommon.

Expert systems are being used to monitor process operations and provide quick process assessments to operators. The real-time requirement coupled with the need for large numbers of rules in real-world problems enforces special expert system design requirements. Moore (Bibliog 37 and 38) provides a good discussion of this.

Overall, considering the results from all the tables, it appears that in the AI family of technologies expert systems are, at this time, enjoying the greatest use in manufacturing applications with vision systems second.

The design and process planning applications are reported mostly by workers associated with the academic or government laboratory community while those for assembly/process control come more from industrial companies. Thus, while the relative number of "in use" reports is similar for all groups, the applications for assembly/process control may be a bit more mature than those for design or planning.

In almost all applications of machine vision, it was used for inspection rather than direct assembly. Also, expert systems are reported being used mostly to aid designers and monitor processes with a man still in the loop. One concludes that the technology is not ready to handle manufacturing activities on an autonomous basis.

In all the articles, there is a sense of having only scratched the surface of the potential capability and usefulness of the technology being applied. It appears that AI will continue to be applied to manufacturing through the development of increasingly sophisticated systems.

3.4 INTERVIEWS AND SUMMARY

These conclusions were then discussed with several people having significant experience in manufacturing/AI applications to see if they correlated with their perceptions. The list of those interviewed along with some summary notes of their comments are contained in Appendix C.

From these discussions it appears that while expert systems do dominate current applications, these are still what would be called "research prototypes". Although the existing sytems are very useful, they are not reliable and maintainable enough to be called production systems. They are not ready to be used autonomously, but do provide useful assistance to human workers.

The next year will be very active for the technology. Many products will appear, but it will not be until the end of the year or longer before the new products appearing qualify as production systems. Even then, the successful applications will initially be very simple.

It is not clear what application will dominate in the near future, although within manufacturing, process control appears a likely candidate. Process control applications may be more mature at this point due to the possibility of making small meaningful test cases.

During the next few years many problems remain to be faced in the application of AI to manufacturing. Included in the list are:

- Understanding how to pick problems that are within the capabilities of the available tools and experience. Much work is underway to improve the general understanding of AI usage. The major aerospace companies are making investments along with the government.
- Real-time issues which will surface as bugs as we apply current tools in increasingly stressful situations.
- Integration issues, both with in-place software and with the total factory organization.

In general, more must be learned about AI by manufacturing engineers and more must be learned about manufacturing requirements by AI practitioners.

Care must be taken to not jump into an AI/ES approach over conventional techniques without careful consideration of the tradeoffs. There will be cases that will be better handled with conventional techniques. Usually, these will be such that a solution can be expressed as an algorithm. It may be possible that the flexibility of the expert system approach will be the most important consideration, however.

4. KEY PARTICIPANTS

In the course of preparing this report some information of a background nature was obtained which may be of use if the reader wishes to follow the current developments or study the subject in greater depth. First various sources of information, such as professional groups, annual conferences, and trade newsletters, are provided. This is followed by descriptions of various U.S. and foreign programs that concern the application of AI to manufacturing. Finally, tables of various products have been included. No attempt has been made to verify the product data, and its inclusion represents no endorsement.

4.1 FOR FURTHER INFORMATION

Professional Groups:

- American Association for Artificial Intelligence (AAAI) Founded in 1979. Has over 2000 members. Holds tutorials, disseminates information through conference proceedings and other publications available to the public. Annually publishes Conference Proceedings and Tutorial Syllabus. Publishes AI Magazine quarterly. Next Convention will be August 18-22, 1986 in Amherst, Massachusetts. Point of contact is Louis G. Robinson, Executive Director, 445 Burgess Drive, Menlo Park, California 94025.

- The Society of Manufacturing Engineers (SME) has established a group for those interested in AI applications in manufacturing. The point of contact at SME is Ms. Carol Piercey, Society of Manufacturing Engineers, One SME Drive, P.O. Box 930, Dearborn, Michigan 48121; (313) 271-1500 (ext 371).

Conferences:

- A conference is sponsored annually by the AAAI. This is considered the prime annual conference by many in the AI field. This year's conference, the ninth International Joint Conference on Artificial Intelligence, was held August 18-23, 1985 at UCLA/Los Angeles, California.
- The first Conference on Artificial Intelligence Applications was sponsored by the Institute of Electrical and Electronic Engineering (IEEE) Computer Society in cooperation with the AAAI, December 5-7, 1984 in Denver, Colorado. In selecting contributions, artificial intelligence was viewed as any machine behavior that in some sense mimics intelligent human behavior. Applications were emphasized, but theory was not excluded. The second conference is planned for December 11-13, 1985 at Miami Beach, Florida.
- The first Annual Artificial Intelligence and Advanced Computer Technology Conference/Exhibition was held April 30 to May 2, 1985 at Long Beach, California. This was the first show to emphasize the commercial aspects of AI. The second conference is planned for April 29 to May 1, 1986 at the same location.
- AUTOFACT is sponsored annually by the Computer and Automated Systems Association of SME (CASA/SME) in conjunction with SME. AUTOFACT provides an educational forum for computer integrated manufacturing (CIM). Last year's conference, AUTOFACT 6, was held October 1-4, 1984 in Anaheim, California. Several of the papers referred to in Tables 1, 2, and 3 of this report came from this conference.

- The Robotic Industries Association (RIA) and Robotics International of SME (RI/SME) sponsor an annual conference and exposition on industrial robots. This year's conference, ROBOTS 9, was held at Cobo Hall in Detroit, Michigan. Several papers dealt with artificial intelligence as applied to robotics in manufacturing environments, and an artificial intelligence tutorial was presented.
- The Manufacturing Productivity Center (MPC) of IIT Research Institute in conjunction with RIA, IFS Ltd (England), and SME has sponsored two conferences on artificial intelligence and robotics to encourage interaction among experts in artificial intelligence, robotics, and applications domains. The most recent, AIRCON 2, was held June 10-11, 1985 in Arlington, Virginia.

Trade Journals and Newsletters:

- The Applied Artificial Intelligence Reporter is a newsletter published monthly by the Intelligent Computer Systems Research Institute, University of Miami, P.O. Box 248235, Coral Gables, Florida 33124.
- Robot Times is a newsletter published by the Robotic Industries Association, P.O. Box 1366, Dearborn, Michigan 48121 (Business Office (313) 271-7800).
- AI Trends is a newsletter published monthly by DM Data Inc, 6900 East Camelback Road, Suite 1000, Scottsdale, Arizona 85251 (602) 945-9620.

4.2 U.S. PROGRAMS

On April 3, 1985 the NSF announced the selection of six universities and two affiliates to establish six multidisciplinary engineering research centers. The concept behind this program is to establish what could eventually be as many as 20 engineering research centers on campuses around the country. These centers should encourage multidisciplinary research on topics likely to have broad industrial applications. Funding for the initial six centers will be $94.5 million over the next 5 years. Additional funds are expected to be attracted from private industry. Three of the six centers directly or indirectly involve AI and manufacturing. They are:

- The Center for Robotic Systems in Microelectronics, at the University of California at Santa Barbara. NSF will supply $14 million over the next 5 years to establish and operate the facility. It will focus on the creation of new technology in flexible automation for semiconductor device fabrication.
- The Center on Systems Research at the University of Maryland in collaboration with Harvard will receive a $16 million 5-year grant to conduct research on the application of artificial intelligence, computer aided engineering, and very large scale integrated circuits to the design of interactive automatic control and communication systems. The Harvard connection will include robotics research.
- The Center for Intelligent Manufacturing Systems at Purdue University will focus on the automation of batch manufacturing of discrete products. The central concept will be to develop an "intelligent" manufacturing system which is capable of a least semiautonomous reasoning to reduce the cost, time and errors involved in batch manufacturing. NSF will provide $17 million over the next 5 years.

The premier funding agency for AI research in the world since the inception of the technology has been DARPA. Current work is carried on through the Strategic Computing program and involves funding of about $200 million a year in various military applications such as an autonomous land vehicle (ALV) for the army, a naval battle management system, and a Pilot's Associate expert system for the Air Force. Although these applications do not directly impact the manufacturing technology, they do drive further technology development that does. Examples are vision and image understanding systems needed for the ALV, natural language understanding needed for the battle management system, and developments in continuous speech understanding for the Pilot's Associate. (2)

The Air Force Wright Aeronautical Laboratories (AFWAL) is devoting special attention to artificial intelligence initiatives. In addition to the AFWAL role as agent for the Pilot's Associate expert system portion of DARPA Strategic Computing program, the Materials Laboratory is planning an institute for research and development into applications of artificial intelligence in manufacturing. The objectives of the institute will be to: "provide new and innovative techniques based upon artificial intelligence concepts to reduce the cost of aerospace batch manufacturing parts, as well as to increase the responsiveness and productivity of factories producing these parts. The full scope of manufacturing activities will be considered, from shop floor functions to manufacturing systems, with particular interest in planning, scheduling, and controlling and in manufacturing/design interactions." (21) The Institute will form a center of excellence that will support the organization and management of artificial intelligence efforts, the acquisition and training of personnel to work the artificial intelligence area as it pertains to manufacturing applications, the development of in-house research capabilities, and the involvement of more university researchers in artificial intelligence applications to manufacturing.

The Department of Defense Manufacturing Technology Advisory Group (MTAG) is the official organization used by the Air Force, Army, and Navy to coordinate their respective manufacturing technology programs in metals, nonmetals, electronics, munitions, inspection/test and computer-aided manufacturing. This coordination involves both government and industrial agencies. The industrial coordination is carried out through liaison with various associations such as the Aerospace Industries Association of America Inc.; American Defense Preparedness Association; Electronic Industries Association; National Machine Tool Builders Association; and the Society of Manufacturing Engineers. The CAD/CAM Subcommittee of MTAG provides the technical analysis and working-level Tri-Service coordination of those Manufacturing Technology Projects employing computers in all aspects of design, engineering and manufacturing engineering. The CAD/CAM Subcommittee is considering sponsoring an AI in Manufacturing Workshop in 1985 to introduce AI to the Department of Defense organic industrial base and identify investment opportunities.

Several expert system application projects are being developed by NASA/JSC. Those currently under development are: Expert Electrical Power System (EXEPS), MCC High-Speed Ground Navigation Console Monitoring and Control (NAVEX), Flight Design System Executive, Automated Rendezvous, MCC Navigation Workstation Executive, DPSD-Computer Fault Detectioon (PRISM), and GDSD-Printer Controller. Those in planning are: Automated Software Development and Verification, Interactive Graphics, KSC-Cargo Scheduler, and Onboard Navigation Monitoring. (22)

A private consortium based in Austin, Texas, MCC has a funding of greater than $50 million. The MCC initial membership consisted of 12 major corporations, including Control Data Corporation, Honeywell, Motorola, and RCA. It is focusing on:

- Microelectronics packaging
- Advanced computer architectures
- CAD/CAM
- Data Base Technology
- Artificial Intelligence

4.3 FOREIGN PROGRAMS

The Japanese Fifth Generation computer project, under the Institute for New Generation Computer Technology (ICOT), is a cooperative government-industry effort which will spend up to a billion dollars during the next 5 years to become an exporter of advanced computer technology. The initial work will be focused on:

- Problem solving and inference systems
- Knowledge-base systems
- Intelligent man-machine interface systems
- Development support systems
- Basic application systems

In 1983 The U.K. Government funded the Alvey Program to stimulate research activity in a number of areas including:

- Software engineering
- Man-machine interface
- Intelligence knowledge-based systems
- Very large-scale integration

By the end of 1984 technical approval had been given for nearly 100 projects involving industry, academe, and research organizations. A major project under this program of interest to the industrial community is the GEC-Design to Product project. This is a demonstration project to prove the feasibility of automating the total production process, from design through manufacture to maintenance in the field. Both Edinburgh and Loughborough Universities will participate in this program. (23)

Another U.K. activity is the Turing Institute, set up as a not-for-profit company by Professor Donald Michie in 1984. The objectives of the Institute are research and technology transfer. The Institute will receive funding from industrial subscribers who will in turn obtain training and information services. (23)

The European Economic Community has put together ESPRIT an AI-related program. This program will be jointly funded by governments and industry up to about $1 billion over the next 5 years. All of the work will be accomplished by coalitions of international corporations.

TABLE 4. COMMERCIAL EXPERT SYSTEM DEVELOPMENT TOOLS

Vendor	Product	Host Computer
Inference Corp.	Automated Reasoning Tool (ART)	VAX (VMS)
Software Architecture and Engineering, Inc.	Knowledge Engineering System (KES)	VAX (VMS or UNIX)
McDonnell Douglas	REVEAL	VAX (VMS)
Teknowledge, Inc.	M.1 S.1	IBM PC VAX-11/750,780(VMS)
The Carnegie Group, Inc.	Knowledge Craft	VAX (VMS)
General Research Corp.	The Intelligent Machine Model (TIMM)	VAX-11/750,780(VMS)
Lisp Machine Inc.	Process Intelligent CONtrol (PICON)	Lambda/PLUS
Human Edge Software Corp.	Expert Edge	IBM PC (512K)
Intellicorp	KEE	
Level Five Research Inc.	INSIGHT 2	IBM PC, DEC Rainbow, Victor 9000

Sources: Schlosberg, J., "Almost Human", Digital Review, May 1985 and company literature.

TABLE 5. COMMERCIAL NATURAL LANGUAGE UNDERSTANDING SYSTEMS

Company	System
Artificial Intelligence Corp. Wartham, MA	INTELLECT
Carnegie Group, Inc. Pittsburgh, PA	PLUME
Cognitive Systems, New Haven, CT	PEARL, MARKETEER, EXPLORER
Excalibur Technologies, Albuquerque, NM	SAVVY
Frey Associates, Amherst, NH	THEMIS
Microrim, Bellevue, WA	CLOUT
Symantec, Sunnyvale, CA	STRAIGHT TALK
Texas Instruments, Dallas, TX	NLMENU, NATURALLINK

Source: Miller, R.K., "Artificial Intelligence: A New Tool for Manufacturing", Manufacturing Engineering, April 1985.

TABLE 6. AI WORKSTATIONS

Company	Symbolics	LMI	Xerox
Name	3670	Lambda	1108
Price	85K	89K	34K
Processor	36 bit	32 bit	32 bit
Memory (Mb)	2-30	2-12	2-3.5
Disk Storage (Mb)	167-474	169-1896	42-315
LAN	Ethernet	Ethernet (optional)	Ethernet
Graphics Resolution	1280X1040	1024X800	1024X800
Languages	Zetalisp Fortran	Zetalispz+ Prolog	Interlisp D

Company	TI	Tektronix	Tektronix	Tektronix
Name	Explorer	TEK 4044	TEK 4405	TEK 4406
Price	53K	12K	15K	24K
Processor	32 bit	32 bit (68010)		(68020)
Memory (Mb)	2-16	1-2	1-4	2-4
Disk Storage (Mb)	112-896	20-60	45	90
LAN	Ethernet	Ethernet (optional)		
Graphics Resolution	1024X 800	640X 480	640X 480	1280X 1024
Languages	Com Lisp Prolog	Smalltalk Franz Lisp Prolog	Smalltalk TEK Common Lisp Franz Lisp MProlog	Smalltalk TEK Common Lisp Franz Lisp MProlog

Sources: Davis, J.R., "Artificial Intelligence: A Meeting of the "Minds"", Today's Office, Vol. 19, No. 8, pp 44-50, Jan. 1985 and "New Product Announcements", Byte, August 1985.

TABLE 7. EXPERT SYSTEM CONTACTS

Automated Reasoning Corp., 290 W. 12th St., Suit 1-D, New York, NY 10014, (212) 206-6331

The Carnegie Group, 650 Commerce Ct. at Station Sq., Pittsburgh, PA 15219, (412) 642-6900

Digital Equipment Corp., 146 Main St., Maynard, MA 01754, (617) 494-5350

Expert-Ease, 206 Fifth Ave., New York, NY 10010, (212) 684-4331

General Research Corp., 5383 Hollister Ave., Santa Barbara, CA 93111, (805) 964-7724

Gold Hill Computers, 163 Harvard St., Cambridge, Ma 02139, (617) 492-2071

Human Edge Software Corp., Palo Alto, California

Inference Corp., 5300 W. Century Blvd., 3rd floor, Los Angeles, CA 90045, (213) 417-7997

InfoTym, 20705 Valley Green Dr., Cupertino, CA 95014, (408) 446-7406

IntelliCorp, 707 Laurel St., Menlo Park, CA 94025, (415) 323-8300

Level 5 Research, 4980 S. A-1-A Highway, Melbourne Beach, FL 32951, (305) 729-9046

LISP Machine, Inc. 6033 W. Century Blvd., Suite 900, Los Angeles, CA 90045, (213) 642-1116

Silogic, 6420 Wilshire Blvd., Suite 2000, Los Angeles, CA 90048, (213) 653-6470

Smart Systems Technology, 6870 Elm St., Suite 300, McLean, VA 22101, (703) 448-8562

Teknowledge, 525 University Ave., Suite 200, Palo Alto, CA 94301, (415) 327-6600

Texas Instruments, Box 809063, Dallas, TX 75380, (800) 527-3500

TABLE 8. THE ARTIFICIAL INTELLIGENCE MARKET
($ millions)

Market Area	1984	1985	1986	1987	1988	1989	1990
Expert Systems	32	55	95	160	270	460	780
Natural-Language Software	32	55	100	175	300	525	920
Computer-Aided Instruction	12	20	30	50	80	125	200
Visual recognition	55	85	130	202	320	490	760
Voice recognition	17	25	40	60	90	130	200
Totals	148	240	395	647	1060	1730	2860

Source: Garvey, C.J., "Near-Term Military Applications of Artificial Intelligence and Robotics", AIRCON 2: Second International Artificial Intelligence and Robotics Conference, Washington, DC, June 10-11, 1985.

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APPENDIX A

BIBLIOGRAPHIC SEARCH STRATEGY

Gloria A. Price

Systems searched:

1. The Defense Research On-Line System (DROLS) technical report data base

   This data base consists of bibliographic records of technical reports submitted to the Defense Technical Information Center in Alexandria, VA.

2. Through Dialog Information Service, the following data bases were searched:

   -- NTIS (National Technical Information Service, U.S. Dept. of Commerce, Springfield, VA.). The NTIS data base consists of government-sponsored research, development, and engineering plus analyses prepared by federal agencies, their contractors or grantees. It includes material from both the hard and soft sciences, including substantial material on technological applications, business procedures, and regulatory matters.

   -- COMPENDEX (Engineering Information, Inc., New York, NY). The COMPENDEX data base is the machine-readable version of the Engineering Index, which provides abstracted information from the world's significant engineering and technological literature. The COMPENDEX data base provides worldwide coverage of approximately 3500 journals and selected government reports and books.

   -- INSPEC (The Institution of Electrical Engineers, London, England). The on-line INSPEC file corresponds to the printed Physics Abstracts, Electrical and Electronics Abstracts, Computer and Control Abstracts, and IT focus. Journal papers, conference proceedings, technical reports, books, patents, and university theses are abstracted and indexed; the total number of journals scanned is approximately 3,000.

   -- ISMEC (Cambridge Scientific Abstracts, Bethesda, MD). ISMEC (Information Service in Mechanical Engineering) indexes significant articles in all aspects of mechanical engineering, production engineering, and engineering management from approximately 250 journals published throughout the world. The primary emphasis is on comprehensive coverage of leading international journals and conferences on mechanical engineering subjects.

   -- EI Engineering Meetings (Engineering Information, Inc., New York, NY). EI Engineering Meetings is an index to significant published proceedings of engineering and technical conferences, symposia, meetings, and colloquia.

Search Strategies

The DTIC technical report search looked for all documents about artificial intelligence or expert systems, excluding those classified or restricted. Results: 192 citations

Two searches were performed on the Dialog system data bases:

-- The strategy for the first search was all material indexed under artificial intelligence and also indexed under robotics. Results: NTIS, 124 citations; COMPENDEX, 40 citations; INSPEC, 51 citations; EI Engineering Meetings, 36 citations.

-- The strategy for the second search was more elaborate, and can be represented by the statement A or (B and C), where A = expert systems, B = artificial intelligence, and C = manufacturing, design, assembly, industrial, production, or automation. Searches were further restricted by date depending on the size of the file. Results: COMPENDEX, 161 citations; ISMEC, 69 citations, NTIS; 54 citations; INSPEC, 89 citations.

APPENDIX B

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APPENDIX C
INTERVIEWS

Mr. Robert J. Didocha - Defense Automation Consultant
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As far as aerospace engineers and management are concerned, there does not exist sufficiently widespread communication with the AI community at a meaningful level that will allow the advancement of the application of AI. The need for cross training is, thus, the main reason for the Air Force's sponsorship of the AI in Manufacturing Institute.

Current plans are for parallel funding of research tasks to the academic community and to industry, once the Air Force AI Institute gets underway.

Mr. Didocha is a member of a subcommittee that has developed the recommendations for research programs and projects that the Air Force will give to the AI Institute's Board of Directors. The formation of the Board is anticipated by December 1985.

Dr. Bob Young - Director of the Industrial Automation Lab
Department of Industrial Engineering
Texas A&M University
College Station, Texas 77843

There are quite a few applications being reported as "in use", but they are usually research prototypes rather than production systems. Thus while they will work as designed, they have not yet developed the reliability and maintainability needed to be useful in a general manufacturing environment. There are a few that are production systems, such as XCON, but only a few at this time.

There are several problems with expert system technology as it now stands. The systems tend to not integrate well with other software, and this will delay wide usage of expert systems. In addition, the criteria for problem solving are not well understood, and this will result in many failures as people pick problems that are too difficult for the tools and experience they have available. Another problem is that in some cases the prototype systems are benchmarked against human workers when the problem could be handled better by a conventional (non-AI) computer program. This leads to false expectations.

The immediate future applications of AI in manufacturing will involve expert systems that are simple stand alone systems, requiring little expertise to implement and a quick turnaround. In the next 5 years many will try applying expert systems to problems that are too complex and thus will fail. Most successes will be with simple problems.

The future impact of AI in general will be in software and information systems development. The technology developed and experience gained will work toward reducing the software life cycle.

In summary, AI is a potentially powerful tool, but it has limitations that are not yet well understood. Those planning to apply the technology soon should be careful.

Dr. Young has just finished a report on the assessment of AI applications to manufacturing for AFWAL Materials Lab Man Science program. The report is being reviewed and should be out soon. It will be available from the Defense Technical Information Center.

Joel Schnur - Manager of Computer Aided Manufacturing
Hughes Aircraft Company
Electro-Optical Manufacturing Division
Chairman of CAM-I Advanced Technical Planning Committee
Chairman of Hughes corporatewide CAM Advisory Group

The Hughes HICLASS (TM) system is one of the first production AI systems in a manufacturing environment. It will probably be one year to 18 months before others appear. The most significant problem to be faced is the integration of the AI applications with the systems currently in place. This includes the total factory infrastructure as well as the individual people within that organization. The development of standards is another essential ingredient to help move the application of the AI technology forward. AI cannot function in isolation. It must comingle and support its environment.

Schnur has been heavily involved in the development of the HICLASS AI system at Hughes (Bibliog 14) and his observations regarding the problems to be expected from the integration requirement come from first hand experience.

Harvey Newquist - Editor, AI Trends Newsletter
DM Data Inc.

With the current emphasis on computer integrated manufacturing, process control is probably one of the top three application areas for AI at this time. All the large industrials, the Fortune 500, are concerned especially as they see the movement to robotics. The other two top application areas are financial and medical.

Production AI systems will arrive in about a year. Current systems are still mostly prototypes. One of the major problems to be faced is to get the AI systems to deal with the real-world. This carries the requirement for real-time response and integration with existing systems. Many bugs in the technology probably exist that won't surface until this requirement is faced in a nonlaboratory environment.

Dr. William B. Gevarter - Author of Intelligent Machines,
Prentice-Hall, 1985
(currently working at NASA Ames Research Center on AI)

We are at a jumping off point with many new applications being unveiled at the International Joint Conference on Artificial Intelligence in August of this year (1985).

Expert Systems are currently the most heavily applied of the AI technologies. Due to a general lack of understanding of the capabilities of development tools and the problem requirements, many attempts at developing complex expert systems may very well end in failure.

All major aerospace companies, Martin Marietta, Boeing, Lockheed, etc, have AI groups. These will typically consist of from about 10 to 60 people with at least one member having formal training in AI. Thus attempts to transfer AI technology to the aerospace community are underway.

The use of AI for real-time applications is a continuing problem. AI tends to be used for slower things such as setting process control parameters and scheduling. Because of computing time required, AI tends to be used for slower activities. Time critical activities are still mostly handled by conventional techniques.

In general, AI should be used only if conventional techniques haven't worked or are unlikely to work. If an algorithm exists for finding a solution use conventional techniques.

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Expert systems represent the most heavily applied AI technology with machine vision second.

The conclusion regarding the greater maturity of process control versus design and planning is reasonable and accurate. It should be observed, however, that there is a significant difference in the degree of difficulty. Process control can start small with meaningful test cases where process planning cannot. Also, planning work is heavy among government and NASA sponsorship. It isn't as well developed among the civilian sector.

LMI has two process control systems on-line with Exxon and Texaco. They have three others working and five more scheduled within the next few months.

The technology isn't ready for autonomous operation. That will come in the next decade. However, it should be emphasized that the "human assistant" role is very important in itself. Computers can detect many more things than humans and sorting out things is a vital task. The 500 alarms at Three Mile Island is an example of the problem.

While the products currently being reported may be research prototypes, the boundary between research prototype and production isn't clear. The current products are not toys. They definitely address real-world problems successfully. It is true that much remains to be added (and will be) in the way of user friendliness, etc; but this will build upon products that have significant functionality now.

Many attempts will be made to address problems that are beyond the capabilities of the tools. That is why LMI works closely with the customer and starts with a prototype to make sure the customer understands exactly what will be able to be done. It will continue to be important for the applications engineer to understand both the problem requirement and the tool capability. This is not a new problem, but has been faced before when any new technology is being tried. A few years ago people had similar problems with adaptive control.

As far as the choice between AI and conventional technology is concerned, the "teachability" aspect of the expert system approach should be emphasized. If the knowledge base of the problem is fixed, then it may be that conventional techniques should be used. If not everything is known, an expert system makes sense. An expert system can easily be modified as new information is uncovered or as new insight into the problem is obtained. The initial attempt at an expert system has been referred to as a "novice system" which only grows into an "expert system" in time as greater experience and insight into the problem is gained with time. XCON, for example, started with 450 chunks of knowledge. The size of the expert system was increased to about 1200 before it performed acceptably at the expert level.

TECHNOLOGY ASSESSMENT OF ARTIFICIAL INTELLIGENCE APPLICATIONS IN MANUFACTURING

Date: September 1985

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